TMA72 TOLERANCE TO SLIGHTLY-CURVED FOLDING FLAT MIRROR

M.Lampton
UCB SSL
4 Nov 2005

To better understand the figure tolerance of our folding flat mirror, I calculated the optical performance of TMA72 in which the folding flat mirror is assigned nonzero curvatures.

First, I calculated the **static total aberration** contributions from (a) curving the flat mirror while leaving all other optics and spacings unchanged; (b) curving the flat mirror but then refocussing the telescope by translating the secondary mirror in Z for best image quality; and (c) curving the flat mirror and then using all five degrees of freedom in secondary mirror adjustment to achieve best image quality. In all cases the image star goal positions were their observed centroids, i.e. the goals floated and image motion introduced by the curved flat or by the secondary mirror did not count as aberrations.

Second, I examined a particular concern raised by M. Krim, that because the flat folding mirror is working at 45 deg to normal incidence, any power that it contributes will also contribute to the system **astigmatism** and therefore its power cannot be compensated by refocussing.

Third, I estimated the curvature to be expected if the flat mirror were ideally fabricated and verified in an isothermal laboratory environment, but then deployed into an on-orbit environment given by Jelinsky's current static thermal model, causing it to undergo a **thermal distortion**.

STATIC TOTAL ABERRATION: The system-level image quality is affected by many contributing factors. The current draft overall RMS PSF goal is 7.7 microns (rss = 59.3 um^2). The division into various contributors is not yet firm. If 5% of this rss budget were to be assigned to aberrations caused by a slightly curved folding flat mirror, this allowance would raise the idealized geometrical blur (3.335 um rms or 11.1um^2 rss) to a total of 3.76 um rms.

For the static figure error study, I employed a ray group with 24 pupil rays per star and 12 star locations, at coordinates (U0,V0) = (6,0), (10,0), (12,0), (14,0), (0,6), (0,10), (0,12), (0,14), (-6,0), (-10,0), (-12,0) and (-14,0) milliradians. Because of my emphasis on the extreme inner and outer ray sets, the absolute blur values computed here are worse than will be obtained by a realistic distribution of pixels, but this angle distribution is convenient in controlling the optimization process which tends to be most demanding at the extreme field angles.

From the table below, with 5 axis adjustment, to raise the total blur to 3.76 um requires a folding flat mirror whose sag is about 8 microns -- 16 waves -- easily detected during mirror fabrication and therefore easily avoided. I conclude that the folding flat is tolerant of curvature and the system blur budget need not anticipate a significant contribution from the folding flat.

TABLE 1: RESULTS, STATIC TOTAL ABERRATION

Curvature 10^-6 recip meters	Sag microns peak-valley	RMS blur microns fixed focus	RMS blur microns adjusted focus	RMS blur microns 5axis secy adj
100	8.00	4.812	4.001	3.706
50	4.00	3.756	3.509	3.427
0	0.00	3.335	3.335	3.335
-50	-4.00	3.767	3.524	3.444
-100	-8.00	4.829	4.025	3.737

ASTIGMATISM. Although total aberrations are adequately described by the rms or rss moments of the PSF, astigmatism is best shown by means of through-focus diagrams in which the tangential (in-plane) blur and sagittal (cross-plane) blur are plotted as functions of the system defocus. If astigmatism were zero, the minima of these two functions would lie at the same focal position. To the extent that their minima occur at different focus positions, astigmatism is present.

Figure 1 below shows six through-focus plots for the ideal configuration of TMA72, whose folding flat mirror has zero curvature. The diagrams are taken at various locations within the image field, specifically at Rinner, Rmid, Router along a northern and a western radius. The focal range shown is +/- 5 microns of secondary mirror travel. As expected, when the secondary mirror departs more than about a micron from its overall best focus position, the aberrations grow rapidly. For this idealized configuration, the northern radius pattern and the eastern radius pattern are the same, except of course that the (u,v) second moments (corresponding to x and y) have interchanged. The black curves are the rss moments, 1.414 times the rms moment.

Then, in Figure 2 below, I show the same set of through-focus plots for TMA72 but with its folding flat mirror altered to give it a curvature Cflat=+1E-4 reciprocal meters. A curvature of this magnitude is sufficient to produce a very-obvious sixteen waves of departure from a flat during test. It is remarkable how similar Fig 2 is to Fig 1: the astigmatism added by the curved flat has very little effect on the relative positions of the sagittal and tangential foci.

I conclude from these through-focus ray traces that our TMA is highly tolerant of astigmatism induced by small amounts of power introduced by the folding mirror.

Fig 1: Astigmatism, ideal TMA72, Cflat=0

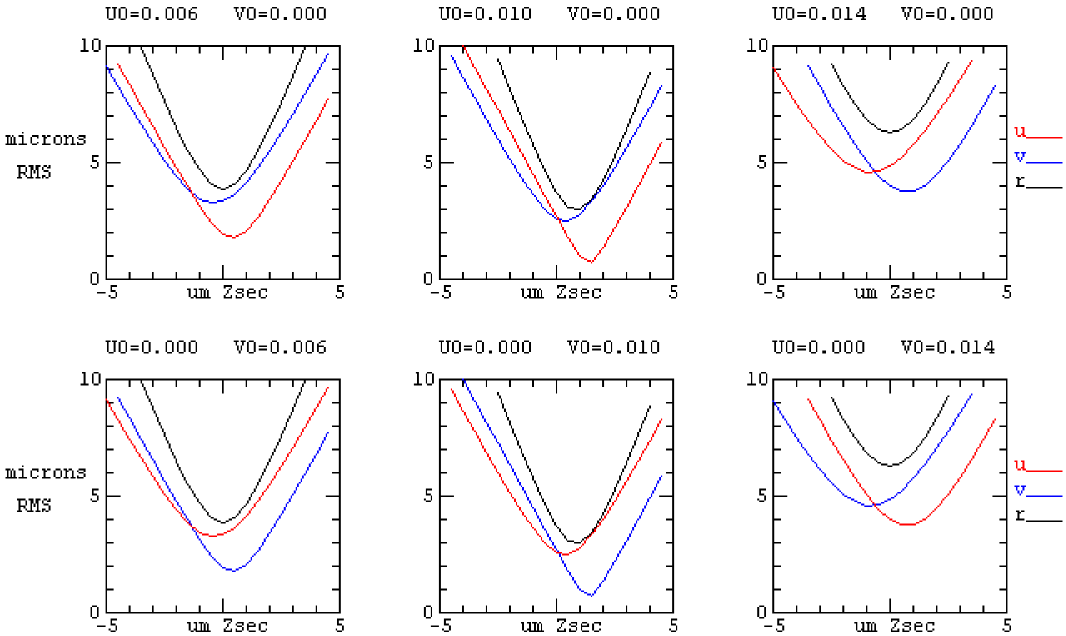
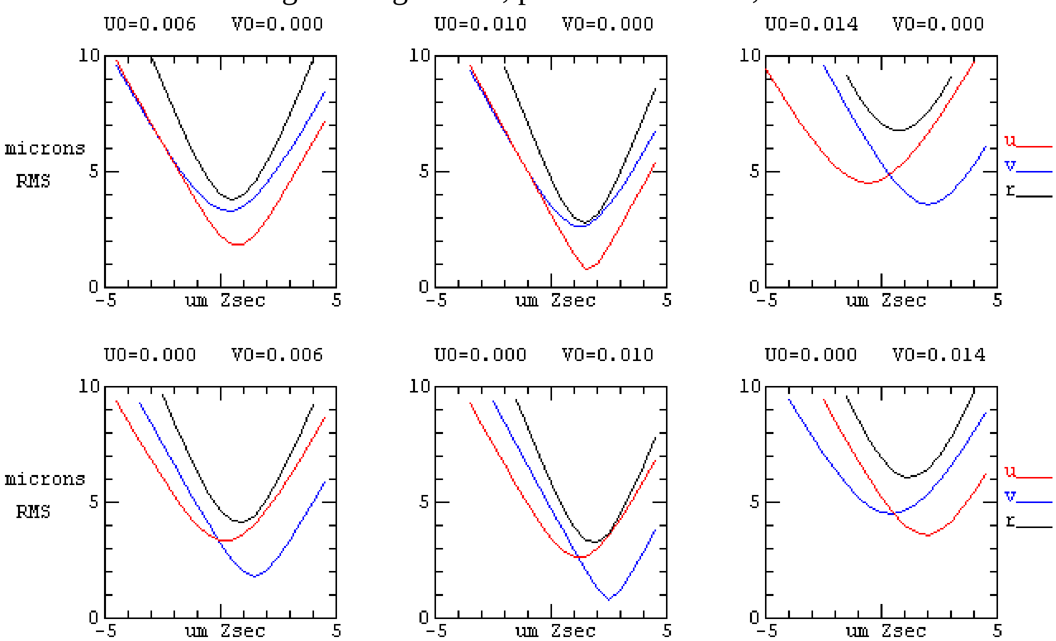


Fig 2: Astigmatism, perturbed TMA72, Cflat=+1E-4

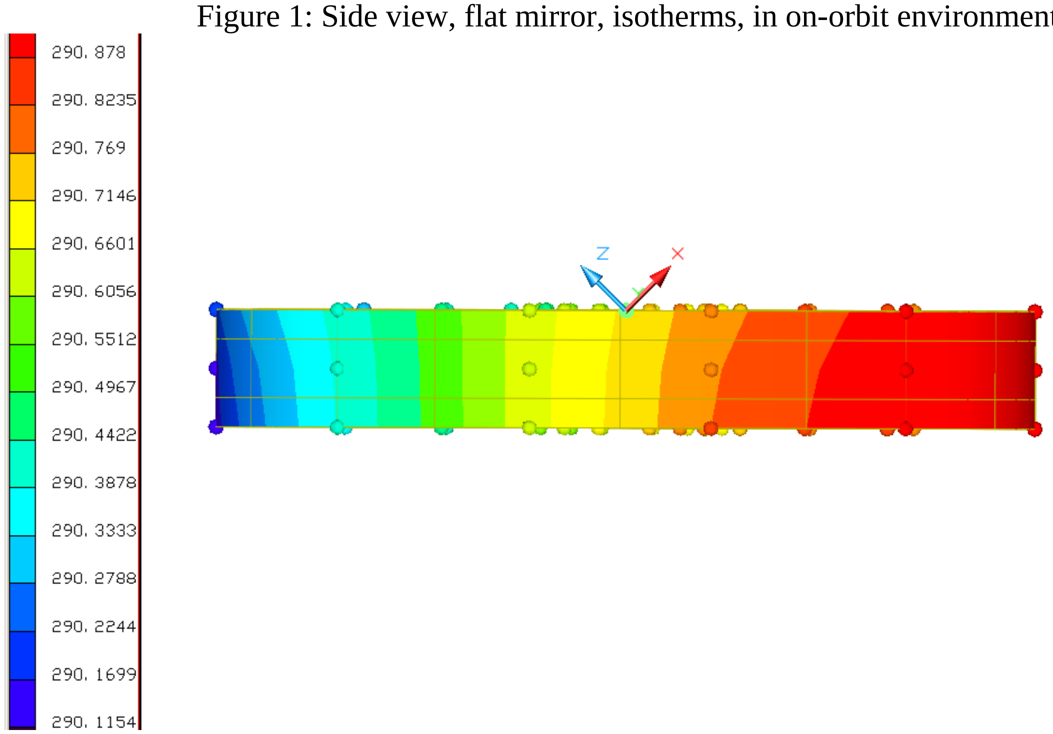


THERMAL DISTORTION. The fabrication and acceptance testing of the flat mirror will take place in an isothermal environment. On orbit however the mirror will be expected to perform with one major thermal perturbation: the cold stop, operating below 200K, will be inserted into the exit pupil port at the center of the mirror. The end of the flat mirror closest to the focal plane will have a large exposure to the insulated cold stop and focal plane and will be expected to operate somewhat colder than the end of the mirror located away from the focal plane.

Jelinsky has prepared a static thermal model of the entire observatory which includes the temperature distribution for a silicon carbide mirror in this environment. A color coded side view of the flat mirror is shown below. Over its 0.7 meter length there is a temperature difference of about 0.7K, and normal to its face there is a much smaller temperature difference.

For an initially flat mirror the lateral gradient has no effect on the mirror surface figure, but the normal temperature gradient combined with SiC's nonzero CTE causes a net curvature of the mirror. The curvature of a beam subject to a normal temperature gradient G is C = CTE * G where CTE=coefficient of thermal expansion. Modelling the flat mirror as a beam of dimensions HxWxL with H=15mm, W=0.5m, L=0.7m, volume=0.005m3, mass 15kg, the end-to-end heat flow is about 1.0 watts. If the normal heat flow is also 1 watt, then the expected normal gradient is F/K = P/KAnormal = 0.02kelvin/meter and the beam curvature CTE * G = 4E-8 reciprocal meters.
This is a thousand times smaller than the static curvatures discussed above, and can be safely neglected.

Figure 1: Side view, flat mirror, isotherms, in on-orbit environment



I conclude that the likely range of mechanical and thermal distortion of the flat mirror will not significantly compromise image quality. Further modelling may be necessary to establish freedom from PSF time variations at the level required by the planned weak lensing measurements.

-end-